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SUMMARY

A central digital data system incorporating a small general purpose digital computer as the heart of the system is described. The system is designed to operate automatically in recording up to 500 voltage and 500 pressure measurements from each of 100 test facilities. Any three test facilities may be recording simultaneously along with data playback by typewriter or plotter to any three of the 100 users. Voltage measurements are recorded at up to 500 samples per second while all pressure measurements are taken during a 10-second interval.

Other important features of the system are as follows: (1) Magnetic-drum storage provides data buffering and storage capacity for test control programs for all 100 experiments. (Service to any 100 users can be provided within 1 sec after request.) (2) The system has a direct magnetic-core interface with a large data-processing digital computer, which permits limited online processing. (3) An alpha-numeric cathode-ray-tube display and keyboard is integrated into the control console for the display and communication of important operating and maintenance information. (4) The system records the data on magnetic tape in the processing computer format.

INTRODUCTION

A central digital data acquisition system for recording steady-state data was developed at the Lewis Research Center and placed in operation in 1954 (ref. 1). This data system has had continued use since that time. The number of users and the volume of data increased so rapidly during the past few years that the data load (from 40 test facilities) could not be handled effectively. Maintenance of mechanical components became a serious problem, and replacement or extensive modification of the system was required.

System studies of several approaches such as the placing of self-contained recording systems in high-use test facilities or the addition of a similar central system to share the load (with minor updating of the existing system) were therefore undertaken. A decision based on these studies was made to replace the central portion of the data system completely with only minimum change in the hardware located in the remote test facilities. In order to meet the fundamental requirement of increased data capacity, a system requirement was made that sufficient storage capacity be provided for up to 100 facility programs with sufficiently fast access time to give service to any of the test facilities within 1 second after a request.

An additional requirement regarding test facility access to the system involves the conflict of two facilities competing for service. In a shared system, the test facilities must either be willing and able to wait their turn or the system design must allow simultaneous service. To avoid the problems of scheduling this large number of diverse users, it was decided that the system would have the capability of recording and playing back data simultaneously from a number of test facilities.

Study indicated that virtually all conflicts could be removed by using three inputs. Therefore, the system was designed to record from any three and playback to any three of 100 users simultaneously. The system specifications include easy expansion capability up to six inputs and six playback channels.

Although existing equipment located at test facilities is limited to 200 voltage and 300 pressure measurements per test facility, the central system can accept up to 500 of each. The overall sampling rate for the voltage measurements is selectable from 1 to 500 samples per second. Direct magnetic-core interfacing with a large processing computer was required to permit on line processing with playback of processed data to the test facility. The analysis indicated that these requirements could be met most economically by using a small general-purpose digital computer rather than a special-purpose controller as the heart of the data system. This opinion was confirmed during the competitive placement of a contract to build the system by the incorporation of this feature in all the proposals.

FACILITY ACQUISITION SYSTEM

Before the elements and operation of the central recording system are described, an understanding of the operation of the facility data acquisition systems is necessary. Figure 1 is a block diagram of the overall recording system. (Central control and recording is described in detail later.) The central area is connected to the facility subsystems by means of a 500 twisted pair, telephone-type cable. The cable, almost 2 miles in length, must carry both the data and the control signals necessary for system operation.

Examination of a test facility shows that both voltage and pressure measurements are taken and that some of the test facilities share a voltage-measuring system. The voltage-measuring systems vary in type from facility to facility, but a typical one would have the following characteristics:

Number of inputs	200
Full-scale input, mV	20
Overall sampling rate, samples/sec	20
Analog to ditial conversion, bits binary coded decimal plus sign	12
Sequential scanning of inputs	

The pressure-measuring system, called DAMPR, was developed at the Lewis Research Center, and its operation is fully explained in reference 1. Briefly, the system consists of a number of differential pressure switches, each with one side connected to an unknown pressure to be measured and the other side to a manifold. The pressure in the manifold is varied from a low to a high pressure and a pressure-time relation developed. Recording the time at which each of the unknown pressures was equal to the varying manifold pressure then allows calculating the unknown pressures with an inaccuracy of approximately ±0.1 percent overall.

The basic elements of the playback portion for the complete system are shown in figure 2. The playback devices, typewriter, facsimile plotter, and printer, were a part of the already existing system and are used with little or no modifications in the present system. With the original system, only data with no computation or scaling were played back to the test engineer. The principal uses for the playbacks are in determining the quality of the data being recorded and in monitoring the progress of the experiment. Playback of computed data is possible with the present system.

The three playback devices may be used for any test facility. The test facility may have any one, two, or all three, depending on its requirements. An automatic typewriter is installed at every test facility. The typewriter operates at 10 characters per second and types on an $8\frac{1}{2}$-inch-wide continuous page. The test engineer may have any number of preselected input signal values printed back in the test area after a recording.

The printer is used where playing back a large number of input signal values is desired and the time of playback on the typewriter would be excessive. The printer, operating at 20 lines per second, prints two data values per line on a continuous strip of paper $2\frac{1}{4}$ inches wide.

The facsimile plotter is used primarily by facilities that have a DAMPR. The device was fashioned at Lewis using a conventional facsimile plotter as the main item. It plots the data at a rate of 15 points per second as a percentage of the scan across the width of paper. A 100-point grid is drawn on alternate scans. The device plots all the input values in sequence. An example of a facsimile plot is shown as figure 3.

CENTRAL CONTROL AND RECORDER

This section describes items of the central control and digital computer. First, an identification and description of the component parts and, second, an operational description of the system are presented.

Components

The physical layout of the system and a block diagram of the central control and recorder are shown in figure 4. The computer has a 6-microsecond memory cycle time and 16 000 words of core memory. Each word consists of 18 bits plus parity and memory guard bits. The computer contains one direct memory access channel. The system contains a time-sharing buffer system to service all inputs and outputs through the direct memory access channel.

A 1 000 000-word magnetic drum supplements the magnetic core storage of the computer. The computer-drum transfer rate is approximately 30 000 words per second. The drum is used to store computer operation routines, test control programs, and data. (In this report, a computer routine refers to a set of computer instructions that defines a task, while a test control program is the list of information the test facility uses to define a data recording.) The large storage of the drum allows all test control programs from all the test facilities, a total of up to 200 programs, to be stored permanently on the drum for random recall within 100 milliseconds.

The system has three high-performance digital tape handlers. They operate at 75 inches per second, 556 bits per inch on 1/2-inch tape. The units have complete pneumatic control with no pinch rollers.

The input-output keyboard and cathode-ray-tube displays extend the flexibility of the control console and define the main operator-machine interface. The keyboard is similar to that of a typewriter but the typed message is assembled in a buffer memory and displayed on the cathode ray tube before the message action commences. The operator is required to verify that the complete message is correct before the machine will begin this defined action. Each of the two displays, mounted side by side, has a total capacity of 1000 characters in 20 lines of 50 characters on a 6- by 8-inch area. A keyboard and one display are shown in figure 5.

The paper-tape reader is a 300-character-per-second photoelectric unit and forms the primary entry path for new computer routines and test programs. A paper-tape punch of 110 characters per second is also available.

The automatic typewriter, facsimile plotter, and printer are the same units described for test facility playback devices. These units serve as monitors so that the central operator may observe the data recorded by any facility. Also, there are two additional typewriters, one with a keyboard and one a "write only." The keyboard unit is used as a backup device to the main input-output keyboard on the console as well as to supply a hard copy record of input-output operation if desired. The write only typewriter maintains a complete operations log of the system that contains a history of all recordings made by the system and the operator-system communications.

System Operation

Overall design characteristics. - The central system is designed to service up to 100 test facilities using up to 32 digitizers (voltage measuring subsystems) and 8 DAMPR units (pressure-measuring subsystems). The system has an input capability of recording independently and simultaneously from any three test facilities while playing back to any three test facilities. Only one of the three recording test facilities may be recording from DAMPR, however. The elapsed time from a test facility request for service to the "ready-to-record" is less than 1 second. The central system is completely automatic in handling the request for normal service from the test facilities, recording the data, providing the requested data playback, monitoring complete system operation, and reporting malfunctions. System operations are defined and sequenced by computer routines. An interface between the magnetic core and a large data processing computer is provided for direct two-way communication. A magnetic tape forms the permanent data record as well as a second path for raw data to the processing computer.

System operation to user. - Prior to the actual experiment, a meeting of the test facility personnel, data recording system personnel, and data computing personnel is held in which the general operations program for the test is planned. At this meeting the elements of the test control program, some of which are given in table I, are determined. A paper tape containing this information is prepared by the data recording system personnel, read into the system, and stored on the magnetic drum for use during recording.

When the test facility personnel wish to make a recording, their first action is to set or to verify three thumb wheel switches on their control panel that define the central test program to be used at the time of the test. A test facility may have up to eight different programs from which to choose. Each facility control panel has a light that indicates when the system is busy. This condition results if three other test facilities are recording or if another test facility is using a common piece of equipment such as the digitizer. Studies of past system load and predicted future load indicate that three inputs will give virtually nonconflicting service.

The test facility operator may place a CALL or a TEST CALL. The CALL signals the central control center of a request for a normal recording, while the TEST CALL requests the action of a normal call but does not record the data on the permanent data record.

When the CALL or TEST CALL signal is received, the system recognizes the calling test facility and reads the switch setting of program number. The requested program is read from the magnetic-drum storage and placed in the active magnetic core.

One of the three input trunks is selected, and line switches connecting the facility systems to this trunk are closed and checked. The START switch on the test facility control panel is lighted, indicating that the test facility may now start the recording.

The START switch may be activated manually by the test facility personnel or by automatic sequencing devices. The digitizer is then commanded to step from one voltage input to the next at a rate dictated by the test control program. The pressure data are acquired by initiating the start of a DAMPR cycle from the central system. The recording may be ended manually or automatically by the test control program.

At the end of a recording cycle, a playback trunk is assigned to the test facility, and playback line switches are closed and checked. The playback of the data just recorded is accomplished automatically as directed by the test control program. If online computing is required, a request for data transfer is made to the large processing computer.

System operation by central operator. - When system operation is viewed from the vantage point of the central operator, the first interest is the operator-machine interface. The operator may communicate with the machine primarily by means of the keyboard on the display console and the function buttons explained later in this section. The keyboard of the typewriter is a secondary input path. Machine-operator communication is done almost exclusively on the cathode-ray-tube displays. An audible signal indicates that an attention message for the operator is being written on one of the displays. The computer console is not a part of the system operations console and is used only in maintenance and checkout.

A typical operator-machine conversation, in which the computer-generated messages are underlined is as follows:

RDG NO ←
<u>FAC</u> 10×10 ←
<u>PROG</u> 123 ←
<u>RDG 320</u>

In the example, the operator wants to know the reading number assigned to the next test recorded from the 10 by 10 test facility using program 123. The operator types RDG NO and then presses the ENTER button on the keyboard. The machine implements a carriage return and request test facility identification by typing <u>FAC</u>. The operator answers 10×10 and presses the ENTER button. The computer asks the program number by typing PROG. When the program number is entered into the machine, it answers the complete question by, for example, typing RDG 320. At this point, the operator may commence another conversation if he desires or he may end the communication.

The main advantage to this type of communication is its flexibility and compactness. There is virtually no limit to the number of different operations and variations that may be questioned and answered in this fashion. The sequence of events in any conversation may be changed, added, or deleted by varying the routines stored in the computer. At present, there are 14 major areas of conversation defined, but several of these have a number of variations, which depend on operator action within the conversation. With all this present flexibility and capability to expand or modify, the control console remains simple, uncluttered, and consolidated.

A limitation to this type of keyboard communication is that it requires the operation of a relatively large number of buttons and a long period of time to complete one function. In order to partly solve this problem, a group of 18 special function switches has been installed on the control console as shown in figure 6. In general, the functions appropriate to special buttons must be defined by a single action and are called for in normal operation. An example is CONTROL PROGRAM INPUT (the first button from the left in the first row, fig. 6). The system operator loads the new paper-tape test control program onto the paper-tape reader and initiates this function. The system reads the paper tape, assembles it into the correct format and places it on the magnetic drum for future use. The 18 function switches on the console are actually only interrupts to 18 separate subroutines already in the machine. Thus, modifying, adding, or deleting items of a function or even the complete function by changing the subroutine is easy.

Central operation during recording. - The action in the central area prior to a test recording has been previously explained in regard to preparation and loading of the test control programs. No central operator action is necessary anywhere in the normal record-playback cycle. The sequence of recording events, however, is displayed on the control console cathode ray tubes as they occur. Both record and playback trunk assignments are displayed along with the status (e.g., call, waiting, running, etc.) of the recording. The elapsed time that a test facility has been assigned an input trunk is also displayed. If calls are waiting to be processed because all three inputs are busy, the waiting test facilities are identified.

During the recording of the data, the data words are received at central control in the magnetic core and routed into the magnetic drum. The temporary storage of data on the magnetic drum allows the complete reading to be assembled before start of recording on magnetic tape. Thus, the three test facilities that may be operating simultaneously can have the data on the magnetic tape as complete readings and not intermixed readings. The data readings are recorded on the magnetic tape chronologically as defined by their start of recording.

There is an additional advantage in storing the data intermediately on the magnetic drum. With the aid of quick playback at the facility, the test engineer can edit the data soon after the experiment is performed. (One example is that of a thermocouple burning out during the experiment; the data from that channel should not be used in computation.) Since a failure of an input is generally discovered one or two readings after the occurrence, a few readings are retained in the drum so that these changes may be made without rerecording on the permanent-record magnetic tape. After a short period of time, perhaps 1/2 hour, the information is recorded on the magnetic tape even if additional readings were not taken.

Special operations. - Although the central operator is not required to assist a normal record and playback cycle, he must act on any change in the test control program or requests for special playback. Table I lists examples of items, which are generally self-explanatory, that the operator may change between recordings. All changes made by the operator are automatically listed by the systems logging typewriter. Changes in the items listed in table I as "Operator cannot change" require that a new program be added to the program storage.

In a system of this complexity, there are several degrees of malfunction. Examples of minor errors that only need reporting are a test facility requesting a program number that is not in drum storage or an error on a magnetic tape readout that does not show on a reread. An example of a serious error is a parity error in the magnetic core of the computer. In all alarm conditions, the machine must call the operator's attention to the display and apprise him of the trouble as well as actions already automatically taken or courses of manual action suggested. The machine uses an audible alarm to call the operator to the system. This alarm is reset by a switch on the console. The operator may take the appropriate action to remedy or bypass the trouble by typing his message through the display keyboard. The system continues to monitor the remaining alarm conditions while any one alarm condition is being serviced so that serious errors will not be bypassed while a minor error is attended.

A housekeeping log of items such as percentage time three inputs are busy, percentage time two inputs are busy, and number of minutes facility X has used the system is constantly maintained in the system. These items, reported on the system log periodically, are used to detect system misuse such as a facility requesting an input far in advance of starting the experiment. This log also allows a better prediction of when and where future system expansion will be necessary.

Finally, low-priority outside tasks may be assigned to the computer system at times when no experimenters require the data acquisition system. These tasks are under acquisition system executive control, which continues to monitor the test facility requests for service. If a CALL is received from a test facility, the low-priority task is immediately deferred and the system readies itself for data acquisition. In general, the low-priority tasks are offline functions required by the acquisition system. An example of this type of function is the translation of new test control programs from test facility experimenter language to computer system language.

CONCLUDING REMARKS

The computer-controlled central data acquisition system described in this report automatically acquires data from three separate experiments selected from a group of 100 potential experiments simultaneously and records on magnetic tape in data process computer format. A small digital computer forms the heart of the central system. Four system features measure its improvement over previous systems:

First, simultaneous input and playback to the users gives virtually nonconflicting service to each user. Although preliminary study of the present laboratory requirements directed system construction with three inputs and three playback channels, the expansion capability to six inputs and six playback channels ensures the future of the nonconflict philosophy.

The second important feature is magnetic-drum storage. Some method of buffering the data between input and writing on magnetic tape is a need in most systems because of formating requirements. With the possibility of several users inputing data simultaneously, the problem of recording on one magnetic tape is compounded, since it would not be reasonable to intermix the individual data values for two or more users. All data from a single experiment cycle, perhaps several minutes in length, are recorded temporarily on the drum, where it is assembled into a reading. Readings are, when complete, recorded on the magnetic tape individually in the proper format. A secondary advantage of temporary storage allows editing the data before it is recorded on the permanent magnetic tape.

The third important feature is the complete storage of all test control programs in an area of fast access. The relatively large storage area of the magnetic drum allows several test control programs for each system user to be accessed quickly into the central magnetic core when needed. This capability allows all users to have access to the system during a short time interval rather than a prescheduled few as required by previous systems because of lack of control program storage.

Fourth, the compact, yet flexible, operations console deserves note. During conceptual discussions, several preliminary hardware designs were considered and rejected because of complexity and large size. The incorporation of the two character cathode-ray-tube displays and keyboard allow a variety of items to be displayed at different times on a very compact display. The character displays have the added advantage of being alpha-numeric and allow a variety of messages to be displayed in written form rather than as abbreviations or in number code. Finally, but perhaps most important, is the ease with which the console may be changed to display the information in a different manner. Even minor changes, such as adding a single switch to a hardware-type console of pushbuttons and indicators, can be a major problem of redesign. The character cathode-ray-tube displays allow the console to remain compact if future usage requires changes to be made in the complete system.

Lewis Research Center,
National Aeronautics and Space Administration,
Cleveland, Ohio, Feburary 20, 1967,
125-23-02-06-22.

REFERENCE

1. Staff of Lewis Research Center: Central Automatic Data Processing System. NACA TN 4212, 1958.

TABLE I. - ELEMENTS OF A TEST

CONTROL PROGRAM

Elements operator can change	Elements operator cannot change
Words to be played back	Program number
Code out words	Facility number
Gain	Number of words in digitizer scan
Reading number	Number of scans in reading
	Number of DAMPR words
	Digitizer rate

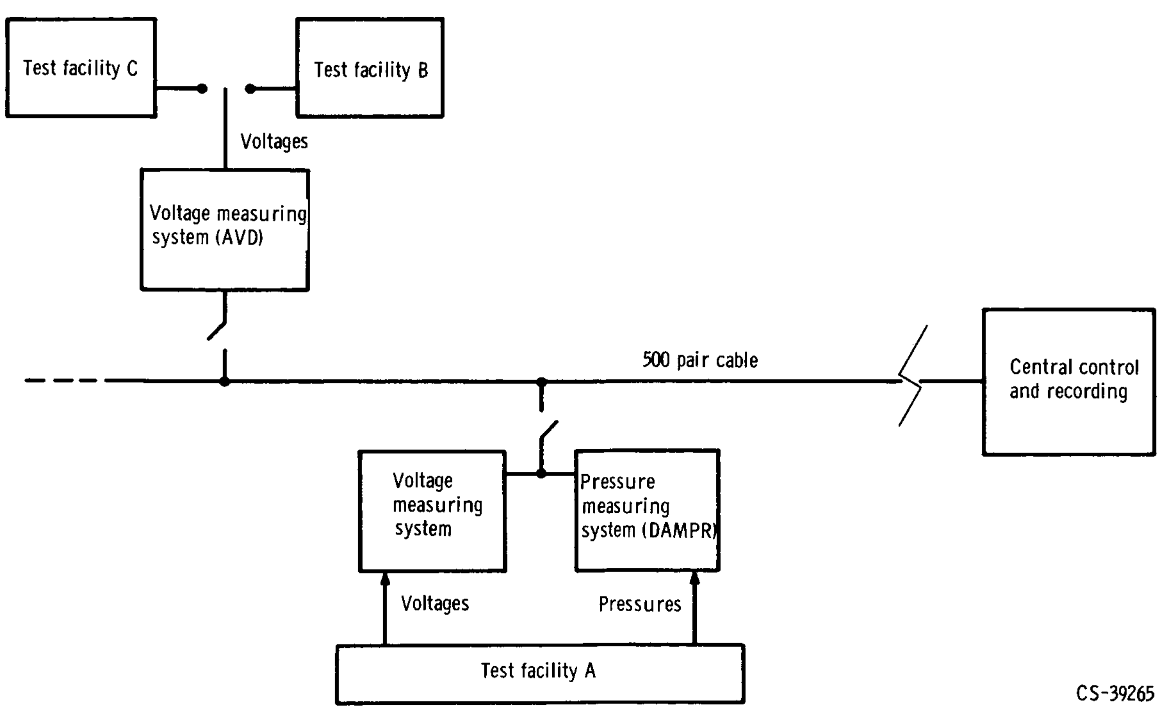


Figure 1. - Overall recording system.

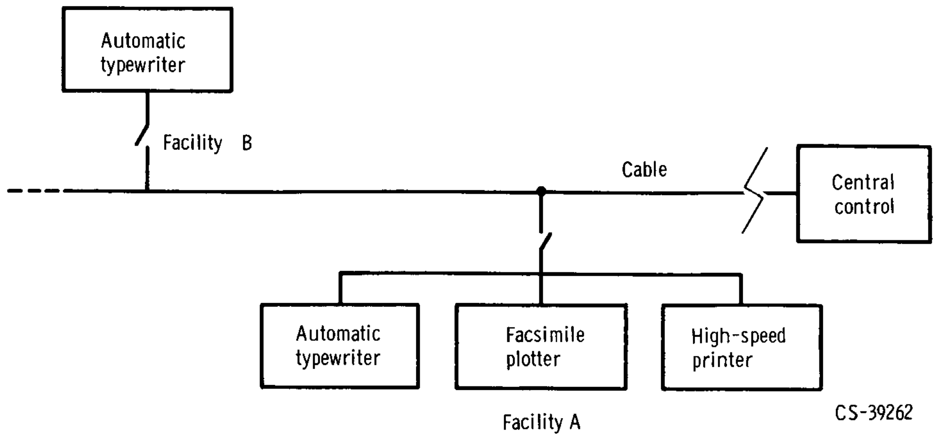


Figure 2. - Overall playback system.

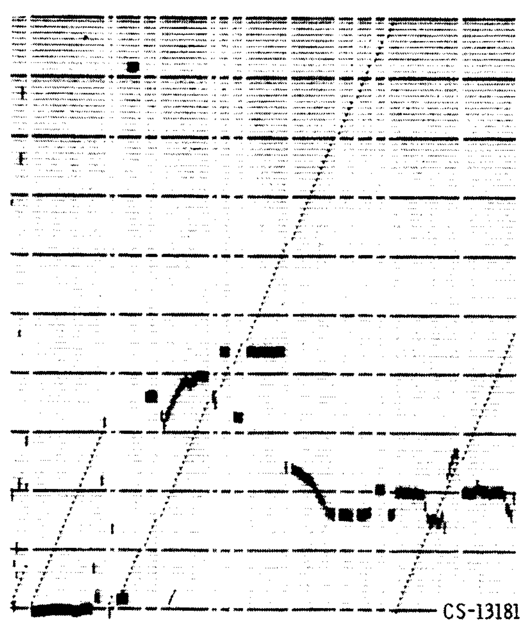
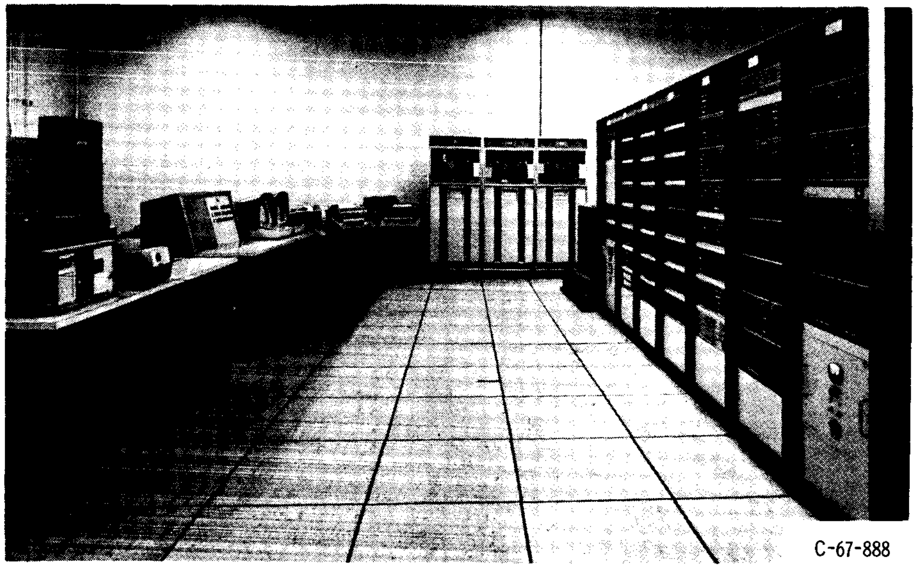
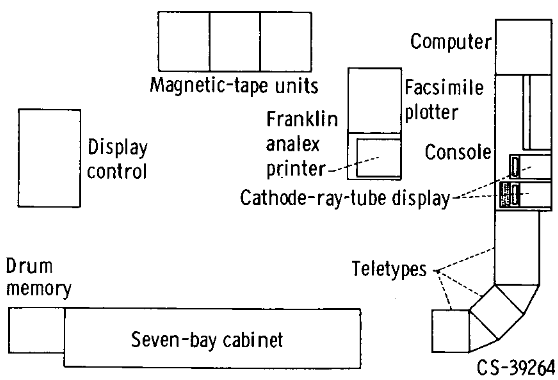


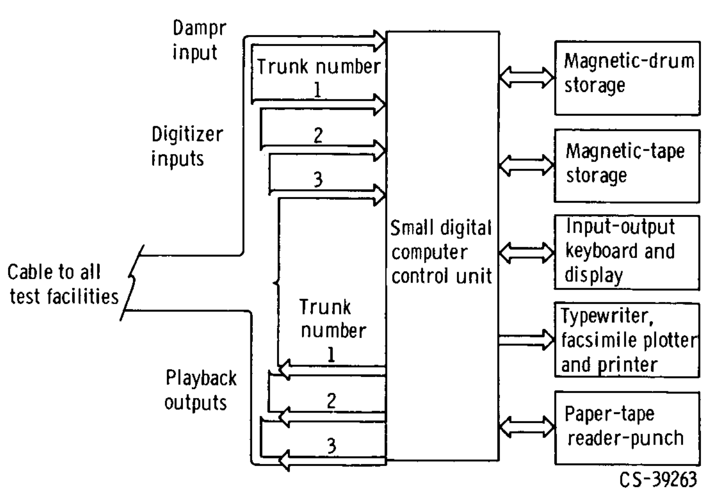
Figure 3. - Facsimile plot of data.



(a) Overall view during construction.



(b) Final equipment layout.



(c) Central control and recorder.

Figure 4. - Electrical connections and physical layout.

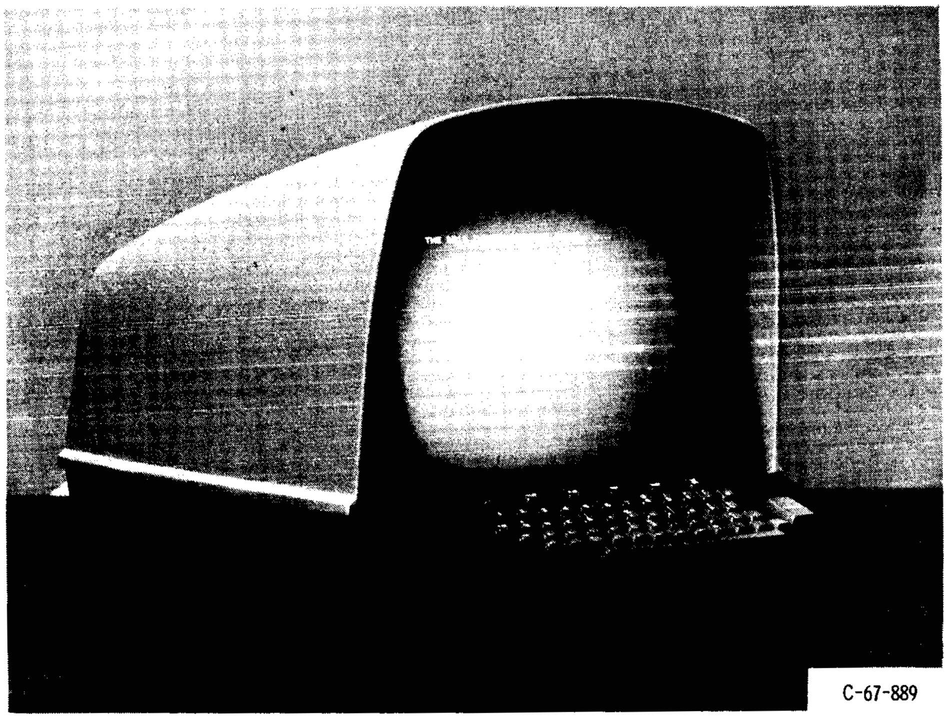


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Figure 5. - Keyboard and display.

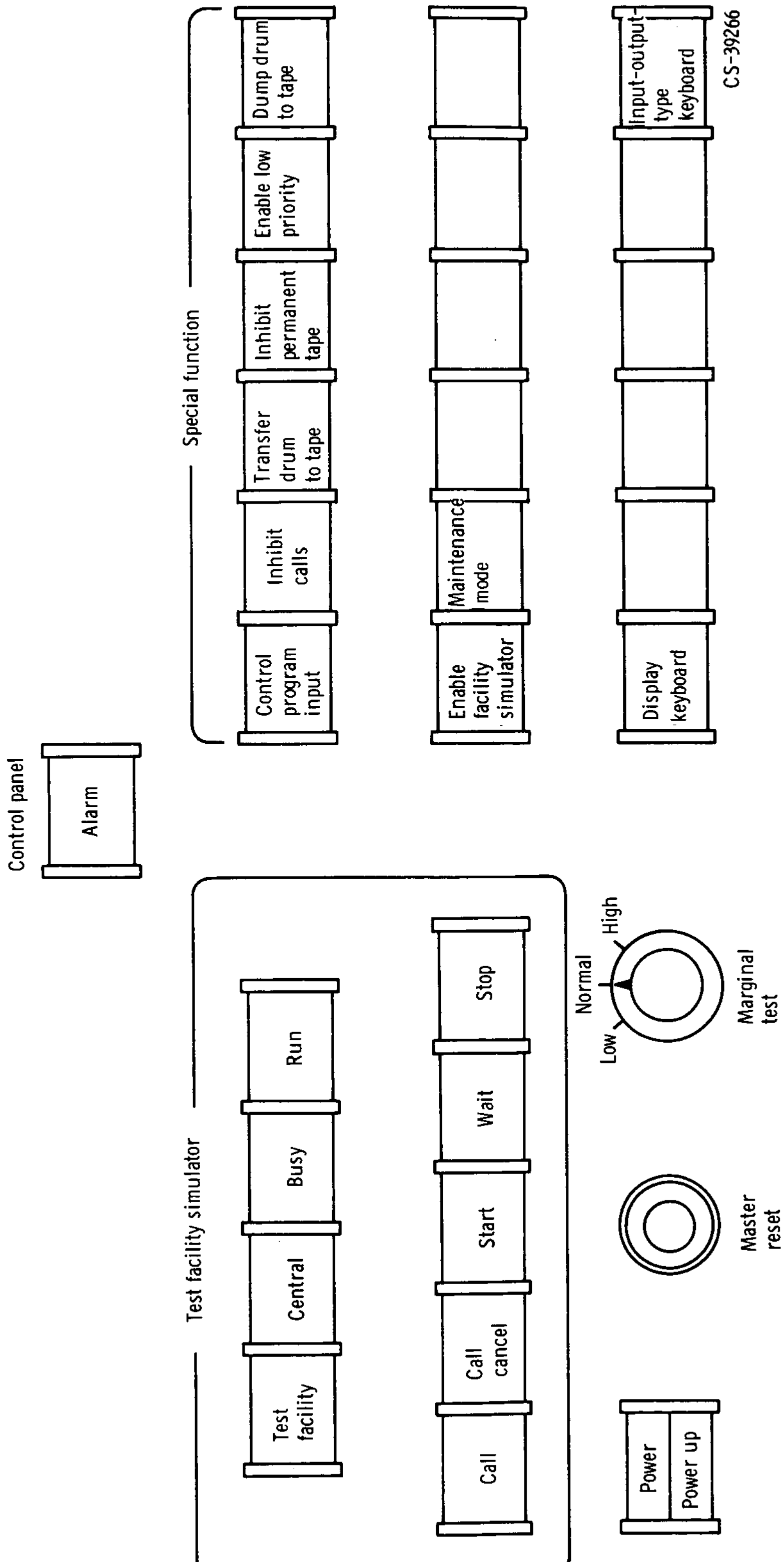

Figure 6. - Supplemental control panel.